The Effects of Sand Sediment Volume Heterogeneities on Sound Propagation and Scattering

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LONG-TERM GOALS

To model the effects of volume heterogeneities in 1) scattering from sand sediments and 2) in sound propagation within those sediments. A better understanding of the role of heterogeneities in both scattering and propagation could lead to improvements in sediment characterization using remote sensing techniques as well as in high-frequency detection of mine and mine-like targets resting on or buried within the seafloor.

OBJECTIVES

The goal of this work is to further develop and test models of volume scattering by utilizing the existing suite of instrumentation previously developed at APL- UW for the study of high-frequency acoustics. These models include perturbation models applied to scattering from the seafloor due to heterogeneities in the sediment properties, recently developed models by Dr. Ivakin [1], which model scattering from inclusions in the sediment such as shells and coarse grains, models which account for the transition layer observed during SAX99 which could have a strong effect on volume scattering at high frequencies, and perturbation theory for sound propagation through a varying poroelastic sediment.

APPROACH

In order to test models of volume scattering, three different experimental approaches are being undertaken; measurements made in the NSWC PC test pond, laboratory measurements in a tank at APL-UW, and measurements in the Gulf of Mexico at the site of the upcoming ONR-supported reverberation experiment. Each of these experiments utilizes the high frequency array previously deployed during the Sediment Acoustics Experiment 2004 (SAX04). This array makes measurements from 200 – 500 kHz and can be mounted on the APL-UW rail tower. The rail tower was deployed in 2010 to collect synthetic aperture sonar images of proud and buried targets and will be deployed again in the Gulf in 2012. The high-frequency scattering data is collected immediately in front of the rail and extending out to 5 meters. The configuration of the array allows data to be collected at grazing angles from 8° to 85°.

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In order to perform the data/model comparisons, extensive environmental measurements are also being made during each of these experiments. These include roughness measurements using the Laser-Line Scanner (LLS), sound speed and attenuation measurements, and the collection of diver cores. These diver cores will be analyzed for high-resolution porosity variations using CT scans as well as for grain size distribution.

In addition to the scattering measurements, model development will focus on connecting the attenuation in the sediment to the scattering from the sediment interface due to volume heterogeneities. This continues previous work developing propagation models that used perturbation theory to model scattering loss for propagation through heterogeneous Biot media. The initial model focused on media in which there were heterogeneities in the frame bulk modulus. The attenuation of the Biot fast wave due to mode conversion into the slow wave was not enough to account for the excess attenuation observed in sand sediments [2]. Attention has now shifted to modeling the effect of heterogeneities in the porosity of the sediment.

WORK COMPLETED

Pond Experiment 2010

Backscatter data from a sand sediment was collected in the NSWC pond in the Spring of 2010 for four different manipulations of the sediment interface: a diver-smoothed surface, a diver-roughened surface, a smooth surface with a distribution of shell pieces placed on the surface, and a smooth surface with the same shell piece distribution flush-buried below the surface. Analysis of this data in 2011 has focused on modeling the scattering from the shell layer. This analysis utilizes the roughness spectra for the shell layer collected using the LLS during the experiment. This spectrum can be well approximated by the spectrum for a random distribution of circular disks despite the irregularity of the shell shapes (Figure 1). The acoustic modeling to this point has utilized Ivakin's unified approach to volume and roughness scattering [3].

Laboratory Experiments

The analysis of the shell scattering data has led to the initiation of a set of laboratory measurements which will focus on scattering from a smoothed sand sediment on which a collection of scatterers will be placed. These experiments will again utilize the high-frequency array, without the rail tower, and the array will instead be mounted in a small fresh water tank. The sand will be placed in a rectangular tray in the base of the tank.

In order to measure both the roughness of the smoothed sand surface and the distribution of scatterers on the surface, the LLS has been modified to operate in the tank. The LLS was originally designed to operate with the In-situ Measurement of Porosity (IMP2) system which has a 4 meter long track over which the LLS collects data. In order to operate in the tank, the LLS has been mounted on a rotation stage such that it can collect high-resolution roughness data in a 20-30 cm diameter circular patch. This system has been constructed and is currently being tested in the APL-UW tank (Figure 2).

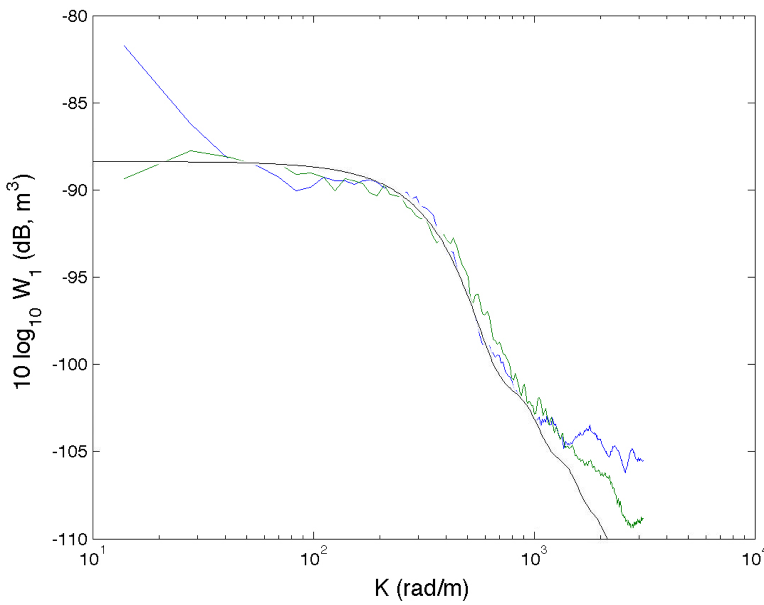

Figure 1: Roughness spectra for a distribution of shell pieces on a smoothed sand surface. The shell pieces were from 1 - 4 mm thick, 5 - 10 mm in diameter, and randomly distributed with a density of 1600 shells/meter. The blue and green lines are the 1-D roughness spectra measured by the LLS along perpendicular lines. The black line is an approximation which assumes a random distribution of circular disks.

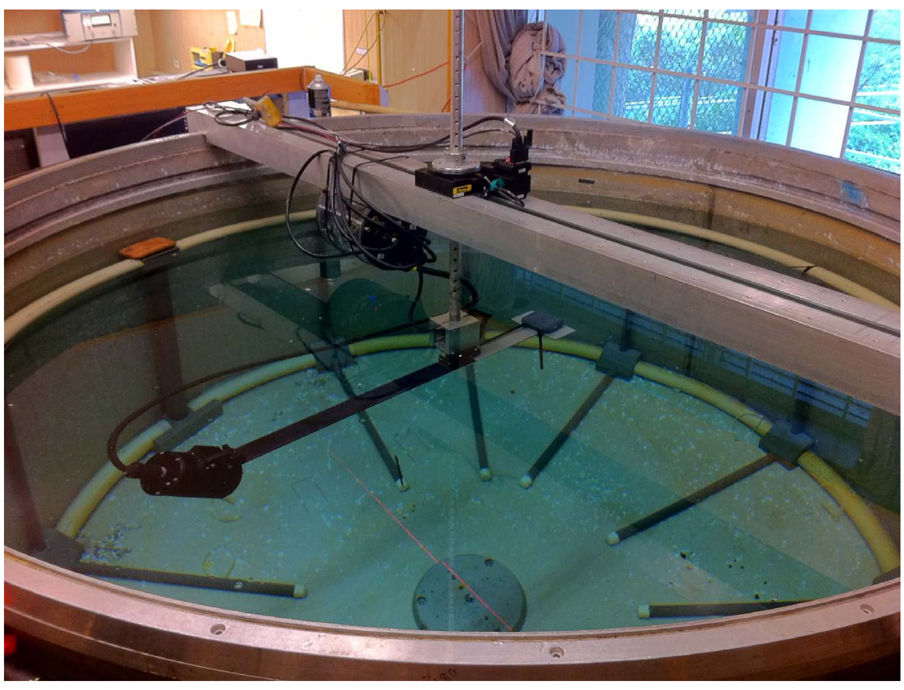

Figure 2: Laser line scanner mounted on a rotation stage in the APL-UW test tank. The laser line is directly below the rotation stage and the line is perpendicular to the camera line of sight. The camera is mounted at the end of the black bar extending to the left. The laser line can be seen at the base of the tank.

Gulf of Mexico Experiments 2011 and 2012

In the spring of 2012, a pilot experiment will take place in the Gulf of Mexico to test systems that will be deployed in a much larger 2013 experiment. During this pilot experiment, the APL-UW rail system will be deployed and this project will leverage that deployment in order to collect data using the high-frequency array. In preparation for that work, environmental measurements were collected in the spring of 2011 during an engineering test at the same location. These measurements included the collection of roughness spectra, sound speed and attenuation within the sediment, and the collection of sediment samples from the site. The analysis of the sediment samples will focus on determining the size distribution of shell fragments at the experiment site. As opposed to the SAX99 and SAX04 sites, this site has a large concentration of shells and shell fragments making it an ideal complement to and continuation of the experiments conducted in the NSWC PC pond in 2010.

The 2011 Gulf of Mexico environmental characterization will also support work with Reson to invert multibeam echosounder (MBES) data for bottom properties. During the 2011 cruise, data was collected with a Reson 7125 at the experiment site from 150 - 450 kHz. These systems are typically used to measure bottom bathymetry, but the raw acoustic returns carry information about the bottom properties as well. This data compliments the data which will be collected using the high frequency array.

Model development

In order to model the propagation loss due to scattering from heterogeneities in the porosity of a poroelastic medium, perturbation theory was applied to the effective density fluid model (EDFM) [4] as a first step towards a full Biot scattering model. While this model will not capture the mode conversion between the fast compressional wave and the slow and shear waves, initial attempts at a full Biot model indicate that these scattering contributions would be weaker than the losses due to the scattered fast waves [5]. The dominant scattering mechanism should therefore be captured in the EDFM propagation for an unconsolidated sediment. A manuscript which develops the EDFM scattering theory is currently in preparation.

RESULTS

Data/model comparisons for the scattering from the shell layer during the 2011 pond experiment show that, for the environmental parameters measured during the experiment, the model underestimates the scattering levels for both the exposed and flush buried shells. These results indicate the need to conduct a set of laboratory experiments were the composition and number density of the scatters can be varied to model the scattering levels due to these variations.

While it is logical that the signal received from the seafloor due to volume scattering should indicate an associated propagation loss within the sediment, it is not immediately apparent whether this additional attenuation is significant. To determine whether this attenuation is significant, the EDFM perturbation theory can be generalized to model propagation through a fluid medium which has heterogeneities in its density and compressibility. This type of medium has often been used as an approximation to a sand sediment when considering scattering from the seafloor due to both roughness and volume heterogeneities. Typical models scattering from the seafloor due to volume heterogeneities have used perturbation theory and the propagation theory developed for this project parallels these scattering theories and captures the same physics [6]. It therefore makes it possible to

model propagation loss for sediments for which volume scattering models have been fit to experimental data.

As an example, Figure 3 shows the attenuation that results when typical sand sediment volume scattering parameters are used in the fluid propagation model. For this example, the fluid was assumed to have a linear attenuation in the absence of scattering. The standard deviation of the density fluctuations was $\sigma_\rho = 0.05$ and the correlation length was 1 cm. For the exponential correlation function used for this example, the attenuation increases as f^2 and then levels out. The increase in attenuation due to scatteing peaks at nearly an order of magnitude larger than when scattering is absent indicating that this may be an important attenuation mechanism.

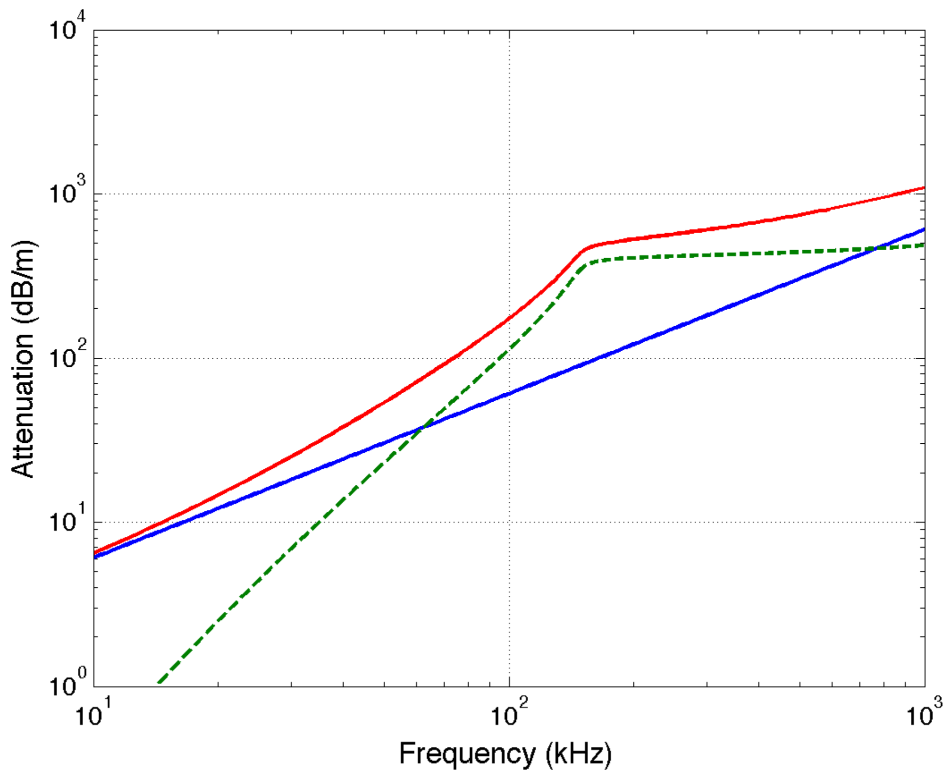

Figure 3: Attenuation in a fluid medium modeled using parameters typically used to model volume scattering in a sandy sediment. In the absence of scattering from heterogeneities (blue line), the attenuation is assumed to be linear. The attenuation with scattering from heterogeneities included is shown as the red line, while the contribution due to scattering alone is shown as the green dashed line.

IMPACT/APPLICATIONS

The results of the measurements and ongoing analysis should help understand the role of volume scattering and scattering from shells in the acoustic characterization of the sediment. This type of information is valuable for the detection of mines both in determining the sediment properties and in determining the background scattering levels which may mask target detection.

RELATED PROJECTS

Title: Mid-frequency reverberation measurements with full companion environmental support
P.I.: Dajun Tang

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